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Test Results and Analysis into Mean Lift-Drag Data

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MINISTRY OF SUPPLY

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Summary.—This report gives the results of tests made in the Royal Aircraft Establishment 24-ft Wind Tunnel on the de Havilland propeller for the Aeronautical Research Council research programme initiated in 1943. The propeller was designed to give a good performance at high forward speeds and the aim of these tests was to check whether, as a result, serious losses in take-off performance had been incurred. The results are more reassuring than was expected.

The principal features of the blades are NACA series 16 sections cambered to a design C_L of 0·3, and very thin root sections (*e.g.*, for $r/R = 0 \cdot 2$, t/c = only 16 per cent). The results have been analysed into lift and drag data for use with the standard single-radius method. The minimum C_D is 0·010 for all tip Mach numbers up to 0·92; $dC_L/d\alpha$ at low incidence is 0·09 per deg; the stalling C_L (*i.e.*, the value for $C_D = 0 \cdot 10$) increases from $0 \cdot 91_5$ at low speed to $0 \cdot 96_5$ at high tip Mach number.

The data have been compared with the results previously found for various Clark Y propellers. When allowance has been made for the effects of thickness at the 0·7 radius, root thickness, pitch distribution and plan form, the low speed stalling C_L for the present propeller is about 0·2 higher than would be estimated for a similar Clark Y propeller. The improvement becomes more marked with increase in Mach number, and so NACA series 16 sections appear to have a beneficial effect on the stalling performance at all tip speeds.

In spite of this difference in stalling C_L, the actual take-off performance is about the same as would be predicted by the R.A.E. charts for their Clark Y blades. This is because the correction for the thinner roots counterbalances the effect of the NACA 16 sections.

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1. *Introduction.*—The Aeronautical Research Council high-speed propeller research programme, initiated in the autumn of 1943, aimed at finding the efficiency of propellers at high forward speeds under the correct operating conditions, and also how the compressibility losses would be affected by three-dimensional and centrifugal effects, and by advance ratio.

Of the three propellers proposed for the tests, the one finally selected, design B, was made by the de Havilland Aircraft Co. Ltd. On the basis of existing data and consistent with structural limitations, this design was considered to be the best possible for operating at a forward speed of 530 m.p.h. at 26,000 ft. The propeller had thin sections of NACA series 16 section shape cambered to a design C_L of 0·3 over most of its length.

The 24-ft Wind Tunnel tests had two principal objects. The first and more important aim was to find how much the design features introduced to improve the top-speed performance had prejudiced the take-off performance—for example, aerofoil tests had predicted that the

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high-speed sections used would give only a poor maximum lift. The secondary aim was to provide a comparison between the data measured under conditions of high tip speed and low forward speed with those obtained from the tunnel and flight tests at high forward speeds. This comparison is important since estimates of performance under flight conditions have had to be based in the past chiefly on the data obtained at low advance ratio. Because of the need for this comparison, the tests were extended to higher tip speeds than would be met at take-off.

The present report gives the results of the tests in the 24-ft Wind Tunnel and their analysis into lift-drag data. A comparison is made of the performance of this propeller with that of Clark Y section propellers previously tested.

2. *Propeller Details and Range of Tests.*—Thickness distribution, plan form and pitch distribution of the propeller tested (design B) is shown in Fig. 1. Figs. 2, 3, 4 compare the blade details of this propeller with those of the second thinned version of the de Havilland *Spitfire* I propeller.

The blade sections outboard of the 0·3 radius were of the NACA series 16 except near the trailing edge where the thickness had to be increased to give the minimum trailing-edge angle considered possible to manufacture.

The propeller was tested at six pitch settings—approximately 10, 15, 20, 25, 30, 35 deg at the 0·7 radius. It was not possible to run the tests accurately at these nominal values because of the method of pitch locking—in the actual tests the blades slipped till they were running about half a degree fine.

Measurements of overall thrust and torque were made over a range of tip Mach number (M_T) from 0·5 to 0·96 and of advance ratio (J) from 0·15 to 0·95. These ranges were the largest possible as determined by the maximum tunnel speed and the power and r.p.m. limitations of the motor.

3. *Results of Tests.*—The results of the tests (given in Tables 1 to 6) have been reduced to the usual coefficients.

Thrust coefficient $K_T = \text{Propulsive thrust}/\rho n^2 D^4$.

Torque coefficient $K_Q = \text{Torque}/\rho n^2 D^5$.

Propulsive efficiency $\eta = (J/2\pi)(K_T/K_Q)$.

The propulsive thrusts are derived by the formula

$$T_p = (T - R) + R_0$$

where
T_p propulsive thrust,
T ' free air ' thrust,
R_0 drag of nacelle and pylon without propeller,
R drag of nacelle and pylon with propeller running,
$T - R$ tunnel balance reading.

The operating conditions are given by the values of advance ratio

$$J = \frac{V}{nD}$$

and tip Mach number $M_T = \sqrt{(V^2 + (\pi n D)^2)}/(\text{speed of sound})$.

4. *Analysis of Results.*—The results have been analysed by Lock's single-radius method[1] into C_D vs. C_L polar curves (Fig. 5) and C_L vs. α curves (Fig. 7). These curves are given for an M_T range from 0·515 to 0·915.

Fig. 6 shows the actual values obtained from the analysis for $M_T = 0{\cdot}615$ and 0·815 and hence the amount of scatter about the mean curves. This scatter is small and there is no break between the curves derived from different pitch settings.

In the above M_T range, the value of $C_{D\,\text{min.}}$ $(= 0{\cdot}010)$ is independent of Mach number (Fig. 5). Between $C_L = 0{\cdot}5$ and $1{\cdot}0$, C_D actually decreases with Mach number and so the stalling C_L (*i.e.*, the value of C_L for which $C_D = 0{\cdot}10$) increases with Mach number—by about 0·05 in this range. For $C_L > 1{\cdot}0$, the C_D vs. C_L curves begin to cross over so that for $C_L > 1{\cdot}2$, C_D increases with Mach number.

5. *Comparison of the Results of the Analysis with Other 24-ft Tunnel Data.*—The results of the present analysis are compared with the data previously described for Clark Y propellers, particularly as regards the stalling performance and the variations with Mach number. The main aim in this comparison is to deduce the effects of the different section shapes but, before this can be done, the influence of other variables has to be eliminated. These other variables are principally the blade pitch distribution, thickness distribution (particularly at the roots), and plan form. The Clark Y sectioned propeller, having the closest similarity to design B in these particulars, and for which data are available[2], is the second thinned version[3] of the de Havilland propeller for the *Spitfire* I. For ease in reference, this propeller is referred to below as propeller V as in R. & M. 2357[4]. Propellers V and design B have approximately the same pitch distributions referred to their respective no-lift angles (Fig. 3) and also similar thickness distributions near the blade tips (Fig. 2). The principal differences that have, therefore, to be allowed for on the basis of comparative data from other designs, are the plan form and the thickness distributions at the roots.

5.1. *Comparison for Low Mach Number.*—5.1.1. *Below the stall.*—Fig. 8 compares the C_D vs. C_L curves for propellers V and design B for a tip Mach number of 0·5 $C_{D\,\text{min.}}$ is the same for both blades $(= 0{\cdot}010)$ but occurs for a slightly lower C_L for design B at about $C_L = 0{\cdot}3$. For higher C_L values, propeller V has the lower drag.

Fig. 9 compares the C_L vs. α curves also for $M_T = 0{\cdot}5$. For 2 deg $> \alpha >$ 8 deg $(dC_L/d\alpha)$ for design B is 0·09 per deg, *i.e.*, 0·9 of the value for propeller V. This agrees with predictions from two-dimensional aerofoil tests. Hence the value of A_0[5] that should be used in 8-radius calculations[5] for propellers with NACA series 16 sections is 0·09 rather than 0·10.

5.1.2. *Stalling behaviour.*—The behaviour at the stall is compared on the basis of the value of C_L for $C_D = 0{\cdot}10$. An empirical method was suggested in R. & M. 2357[4] for allowing for the effects of different design parameters on this C_L value. These effects are assumed to be mutually independent. The following is an application of this method to propellers V and design B.

Difference in design	Effect on 'stalling' C_L (i.e., C_L for $C_D = 0{\cdot}10$)
1 *Pitch distribution* (Fig. 3) *Thickness distribution at the tips* (Fig. 4)	
No appreciable differences	No effect.
2 *Thickness ratio at* $0{\cdot}7$ *radius* (Fig. 2)	
Design B thicker by $\frac{1}{2}$ per cent.	C_L, $0{\cdot}05$ higher for design B than for propeller V
3 *Root thickness* (Fig. 2)	
Suggested criterion: fractional radius for which thickness ratio = 30 per cent.	C_L, $0{\cdot}28$ lower for design B (on basis of R. & M. 1849[1])
Design B: $r/R = 0{\cdot}17$	
Propeller V: $r/R = 0{\cdot}32$	
4 *Plan form* (Fig. 4)	
(Analysis allows for differences in solidity at $0{\cdot}7$ radius)	
(a) Differences near blade tips: design B narrower—difference about a quarter of that between R.A.4014 and *Hornet* paddle blade compared in R. & M. 2493[6].	C_L, $0{\cdot}03$ lower for design B.
(b) Differences near blade roots: design B appreciably wider and hence when blades are operating at same C_L at $0{\cdot}7$ radius, design B has lower C_L over inner radii. Calculations indicate difference not more than 2 per cent.	C_L not more than $0{\cdot}02$ higher for design B.

Adding up the above effects, it is found that for these reasons, the stalling C_L for design B were it Clark Y sectioned should be about $0{\cdot}24$ lower than for propeller V. It is actually only about $0{\cdot}05$ lower (Fig. 8). While it must be admitted that some of the allowances made above, particularly for root thickness, were extrapolated, it is justifiable to conclude that much of the gain of $0{\cdot}19$ in stalling C_L is due to the use of NACA series 16 sections in place of Clark Y. The gain is probably true of all blade radii and not merely the roots.

Possible causes of the unexpectedly good stalling performance of the NACA 16 section are as follows:—

The maximum lift coefficient obtained from analysis of propeller test reults rarely agrees with that found from two-dimensional aerofoil tests, and there are two main reasons for this difference. The first is that the break-down of lift at any particular section of the blade is actually delayed by the centrifugal acceleration, which provides a kind of boundary-layer suction. It seems likely that the NACA series 16 section, with its early stall, presumably due to laminar separation, would be capable of more improvement by suction than a conventional section. The second reason arises from the variation of incidence along the length of the blade which has the effect of averaging out the lift over a range of several degrees of incidence. Thus a section such as Clark Y, whose lift-incidence curve has a sharp peak at its maximum, may show up worse on a propeller than one such as NACA 16 with a flat-topped curve, even though the $C_{L\text{max.}}$ may be lower in the second case.

5.2. *Mach Number Effects.*—When the tip Mach number has increased to $0 \cdot 9$, the improvement in the performance of design B over what would be expected from the results of propeller V is even more marked. From Fig. 10, it can be seen that $C_{D\min.}$ is $0 \cdot 010$ compared with $0 \cdot 012$ for V, the stalling C_L is about the same for the two propellers and above the stall, design B has the lower drag. This agreement in stalling C_L implies that the value for design B is higher by about $0 \cdot 25$ than what would be expected for a similar Clark Y propeller. The further relative improvement of the NACA series 16 with increasing Mach number could be predicted from two-dimensional data which show that, though $C_{L\max.}$ decreases with increasing M for conventional sections, it may remain roughly constant or even increase up to moderately high M for sections with far back maximum thickness.

6. *Comparison with Previous American Model Tests.*—Fig. 11 shows a comparison of C_D vs. C_L polars at low Mach number for design B and a model NACA 16 sectioned Hamilton propeller 6457-6. The results of tests[7] on the latter were analysed in Ref. 8. The model propeller has a design C_L of about $0 \cdot 45$ and bearing in mind that the stalling C_L should increase with the design C_L, the stalling C_L of design B is better than would be expected. The discrepancy may be due to the higher operating Reynolds number of the 24-ft Tunnel tests.

7. *Comparison of Take-off Thrust Characteristics.*—The data resulting from the analysis for design B have been used to derive the static and take-off thrust characteristics for a 3-bladed propeller of $0 \cdot 09$ solidity and $6 \cdot 4$ per cent thickness ratio at the $0 \cdot 7$ radius and having NACA series 16 sections cambered to a design C_L of $0 \cdot 3$ outboard of the $0 \cdot 3$ radius. The results are given in Fig. 12 in the form of curves of K_T/C_p vs. C_p and are compared with values for a similar Clark Y propeller derived from the charts of R. & M. 2358[9]. It had been expected in view of its thin roots and the relatively low design C_L of its sections, that design B would have a particularly low take-off thrust. Fig. 12 shows, however, that while this is true at the low end of the C_p scale, there is little to choose between the two propeller types for high power absorptions. In practice, the latter is now the most important range.

The thin roots and NACA series 16 sections were introduced to improve the top speed performance. Results of high-speed tunnel tests[10] on a model of this propeller have confirmed the expectations of good peak efficiencies up to forward Mach numbers of about $0 \cdot 78$ and so the present results are very important in showing that this has been achieved without any serious loss in take-off performance as compared with a more conventional design.

8. *Conclusions.*—The analysis of the 24-ft Tunnel results on the design B propeller into mean lift-drag data shows that $dC_L/d\alpha$ at low speed $= 0 \cdot 09$ per deg, $C_{D\min.} = 0 \cdot 010$ and is independent of Mach number up to $M_T = 0 \cdot 92$ and the stalling C_L (for $C_D = 0 \cdot 10$) increases from $0 \cdot 91_5$ at low Mach number to $0 \cdot 96_5$ for $M_T = 0 \cdot 92$.

A comparison with earlier results shows that, when allowance is made for the effects of thickness distribution, plan form and pitch distribution, the stalling C_L is higher by $0 \cdot 19$ at low Mach number and by about $0 \cdot 25$ for $M_T = 0 \cdot 9$ than would be expected for a similar Clark Y sectioned propeller. This beneficial effect of the NACA series 16 sections is probably due to the altered nature of the stall on sections with far back maximum thickness.

In spite of this difference in stalling C_L, the actual take-off performance—in particular, for the high power absorptions likely in practice—is about the same as would be predicted by the R.A.E. charts for thin Clark Y blades. This is because the correction for the thinner roots counterbalances the effect of the NACA 16 sections.

These conclusions are more reassuring than had been expected. The good top-speed efficienciencies with this propeller[10] have been achieved without any serious loss in take-off performance.

LIST OF SYMBOLS

D	Propeller diameter.	
R	Propeller tip radius.	
c	Blade section chord.	
t	Blade section thickness.	
C_L	Mean lift coefficient	Derived by single radius method.
C_D	Mean drag coefficient	
V	Forward speed.	
n	Propeller rotational speeed.	
$J = V/nD$	Advance ratio.	
$M_T = \sqrt{\{V^2 + (\pi nD)^2\}}$	tip Mach number.	
ρ	Air density.	
θ	Propeller blade angle (relative to chord).	
ε_0	Angle for zero lift at low speed.	
α	Mean blade incidence.	

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TABLE 1

de Havilland Laminar Flow Blade Propeller (Design B)

NACA series 16 sections, 11-ft diameter, 2 blades

$s_{0\cdot7} = 0\cdot075$, $(t/c)_{0\cdot7} = 0\cdot064$, $\theta_{0\cdot7} = 10$ deg.

N r.p.m.	M_T	J	K_Q	K_T	η
1200	0·613	0·141	0·00267	0·0471	0·396
	0·615	0·271	0·00213	0·0290	0·587
	0·617	0·366	0·00146	0·0134	0·534
	0·618	0·458	0·00061	− 0·0030	—
1400	0·715	0·150	0·00770	0·0479	0·423
	0·716	0·236	0·00231	0·0341	0·554
	0·717	0·314	0·00185	0·0217	0·584
	0·718	0·393	0·00122	0·0072	0·371
	0·721	0·474	0·00039	− 0·0081	—
1600	0·816	0·137	0·00286	0·0500	0·382
	0·818	0·207	0·00254	0·0393	0·510
	0·818	0·276	0·00219	0·0287	0·572
	0·820	0·345	0·00168	0·0163	0·535

TABLE 2

de Havilland Laminar Flow Blade Propeller (Design B)

NACA series 16 sections, 11-ft diameter, 2 blades

$s_{0\cdot 7} = 0\cdot 075,\quad (t/c)_{0\cdot 7} = 0\cdot 064,\quad \theta_{0\cdot 7} = 15$ deg.

N r.p.m.	M_T	J	K_Q	K_T	η
1200	0·619	0·172	0·00536	0·0738	0·377
	0·620	0·274	0·00464	0·0606	0·570
	0·622	0·367	0·00398	0·0472	0·691
	0·621	0·456	0·00302	0·0316	0·758
	0·624	0·551	0·00185	0·0146	0·691
1400	0·723	0·173	0·00556	0·0754	0·372
	0·725	0·237	0·00516	0·0682	0·497
	0·726	0·313	0·00464	0·0573	0·616
	0·726	0·391	0·00398	0·0449	0·700
	0·728	0·471	0·00310	0·0305	0·735
	0·730	0·548	0·00205	0·0163	0·692
	0·732	0·624	0·00085	0·0017	0·201
1600	0·822	0·173	0·00586	0·0793	0·371
	0·823	0·204	0·00550	0·0743	0·437
	0·825	0·273	0·00506	0·0644	0·549
	0·826	0·341	0·00452	0·0538	0·642
	0·827	0·411	0·00386	0·0414	0·707
	0·828	0·480	0·00292	0·0287	0·749
	0·830	0·548	0·00204	0·0158	0·675
1700	0·876	0·175	0·00590	0·0820	0·385
	0·876	0·258	0·00536	0·0691	0·528
	0·877	0·322	0·00485	0·0583	0·614
	0·879	0·387	0·00425	0·0473	0·683
	0·880	0·451	0·00342	0·0341	0·715
	0·882	0·514	0·00250	0·0213	0·698
	0·880	0·550	0·00194	0·0139	0·626
1800	0·923	0·174	0·00634	0·0842	0·366
	0·924	0·243	0·00569	0·0726	0·495
	0·926	0·303	0·00510	0·0620	0·584
	0·927	0·366	0·00453	0·0513	0·658
	0·928	0·428	0·00382	0·0395	0·700
	0·930	0·488	0·00296	0·0267	0·698
	0·930	0·519	0·00242	0·0201	0·683

TABLE 3

de Havilland Laminar Flow Blade Propeller (Design B)

NACA series 16 sections, 11-ft diameter, 2 blades

$s_{0\cdot7} = 0\cdot075$, $(t/c)_{0\cdot7} = 0\cdot064$, $\theta_{0\cdot7} = 20$ deg.

N r.p.m.	M_T	J	K_Q	K_T	η
1000	0·512	0·203	0·00973	0·0954	0·317
	0·514	0·338	0·00832	0·0820	0·528
	0·516	0·447	0·00723	0·0692	0·678
	0·518	0·558	0·00591	0·0517	0·774
	0·520	0·674	0·00411	0·0315	0·819
	0·523	0·784	0·00214	0·0134	0·779
1200	0·610	0·195	0·00990	0·0964	0·301
	0·612	0·279	0·00910	0·0889	0·431
	0·614	0·372	0·00803	0·0786	0·577
	0·616	0·466	0·00707	0·0669	0·700
	0·619	0·561	0·00585	0·0508	0·777
	0·622	0·655	0·00441	0·0344	0·812
	0·624	0·746	0·00282	0·0191	0·801
	0·627	0·794	0·00185	0·0115	0·788
1400	0·712	0·196	0·01044	0·0993	0·296
	0·714	0·320	0·00897	0·0875	0·495
	0·717	0·399	0·00802	0·0773	0·611
	0·719	0·482	0·00712	0·0658	0·705
	0·721	0·562	0·00596	0·0510	0·764
	0·723	0·641	0·00478	0·0371	0·788
	0·724	0·684	0·00399	0·0293	0·798
1600	0·810	0·281	0·00997	0·0969	0·434
	0·812	0·351	0·00909	0·0876	0·538
	0·814	0·423	0·00810	0·0770	0·637
	0·816	0·493	0·00725	0·0658	0·710
	0·819	0·563	0·00622	0·0527	0·756
	0·821	0·599	0·00569	0·0459	0·766
1700	0·858	0·265	0·01074	0·1016	0·398
	0·860	0·331	0·00987	0·0946	0·504
	0·862	0·399	0·00887	0·0838	0·599
	0·858	0·464	0·00780	0·0716	0·678
	0·860	0·530	0·00690	0·0604	0·739
	0·866	0·562	0·00655	0·0552	0·753
1800	0·908	0·251	0·01117	0·1038	0·370
	0·910	0·313	0·01051	0·0983	0·465
	0·912	0·377	0·00967	0·0903	0·558
	0·910	0·439	0·00869	0·0800	0·644
	0·912	0·500	0·00771	0·0686	0·708
	0·914	0·533	0·00712	0·0616	0·733

TABLE 4

de Havilland Laminar Flow Blade Propeller (Design B)

NACA series 16 sections, 11-ft diameter, 2 blades

$s_{0\cdot7} = 0\cdot075$, $(t/c)_{0\cdot7} = 0\cdot064$, $\theta_{0\cdot7} = 25$ deg.

N r.p.m.	M_T	J	K_Q	K_T	η
1000	0·510	0·230	0·01795	0·1164	0·237
	0·512	0·333	0·01660	0·1097	0·349
	0·514	0·447	0·01492	0·1014	0·483
	0·516	0·554	0·01342	0·0924	0·607
	0·521	0·668	0·01166	0·0796	0·735
	0·524	0·777	0·00944	0·0626	0·818
	0·528	0·885	0·00740	0·0440	0·833
	0·530	0·945	0·00608	0·0328	0·809
1200	0·607	0·222	0·01806	0·1165	0·227
	0·609	0·278	0·01747	0·1131	0·286
	0·612	0·370	0·01644	0·1077	0·385
	0·615	0·463	0·01512	0·1014	0·493
	0·618	0·555	0·01346	0·0928	0·610
	0·620	0·649	0·01202	0·0815	0·702
	0·622	0·739	0·01040	0·0690	0·777
	0·624	0·792	0·00912	0·0581	0·800
1300	0·658	0·220	0·01809	0·1160	0·224
	0·660	0·343	0·01689	0·1098	0·354
	0·662	0·427	0·01571	0·1045	0·451
	0·667	0·514	0·01446	0·0975	0·552
	0·668	0·599	0·01312	0·0896	0·650
	0·670	0·682	0·01172	0·0788	0·729
	0·673	0·729	0·01045	0·0696	0·772
1400	0·713	0·219	0·01812	0·1157	0·222
	0·714	0·316	0·01726	0·1113	0·324
	0·716	0·395	0·01636	0·1077	0·414
	0·718	0·477	0·01530	0·1020	0·505
	0·720	0·556	0·01406	0·0953	0·598
	0·720	0·636	0·01250	0·0859	0·692
	0·726	0·674	0·01208	0·0820	0·726
1500	0·759	0·217	0·01840	0·1164	0·217
	0·762	0·296	0·01760	0·1122	0·299
	0·765	0·369	0·01686	0·1096	0·381
	0·764	0·445	0·01590	0·1062	0·472
	0·766	0·519	0·01492	0·1010	0·557
	0·769	0·592	0·01385	0·0941	0·638
	0·772	0·630	—	0·0908	0·680
1600	0·810	0·348	0·01727	0·1113	0·357
	0·814	0·417	0·01670	0·1094	0·434
	0·816	0·487	0·01595	0·1057	0·512
	0·819	0·554	0·01505	0·1015	0·594
	0·821	0·591	0·01467	0·0987	0·633

TABLE 5

de Havilland Laminar Flow Blade Propeller (Design B)

NACA series 16 sections, 11-ft diameter, 2 blades

$s_{0\cdot 7} = 0\cdot 075$, $(t/c)_{0\cdot 7} = 0\cdot 064$, $\theta_{0\cdot 7} = 30$ deg.

N r.p.m.	M_T	J	K_Q	K_T	η
1000	0·512	0·245	0·02443	0·1284	0·205
	0·513	0·333	0·02369	0·1237	0·276
	0·515	0·445	0·02212	0·1164	0·372
	0·517	0·556	0·02078	0·1104	0·468
	0·519	0·669	0·01904	0·1035	0·577
	0·522	0·781	0·01686	0·0922	0·678
	0·526	0·890	0·01473	0·0799	0·766
	0·529	0·949	0·01307	0·0693	0·800
1200	0·609	0·242	0·02440	0·1271	0·200
	0·612	0·374	0·02284	0·1183	0·307
	0·615	0·465	0·02163	0·1134	0·387
	0·617	0·560	0·02038	0·1080	0·471
	0·620	0·651	0·01919	0·1031	0·556
	0·622	0·744	0·01780	0·0970	0·644
	0·624	0·792	0·01691	0·0914	0·679

TABLE 6

de Havilland Laminar Flow Blade Propeller (Design B)

NACA series 16 sections, 11-ft diameter, 2 blades

$s_{0\cdot7} = 0\cdot075$, $(t/c)_{0\cdot7} = 0\cdot064$, $\theta_{0\cdot7} = 35$ deg.

N r.p.m.	M_T	J	K_Q	K_T	η
1000	0·510	0·258	0·03214	0·1384	0·176
	0·511	0·335	0·03067	0·1318	0·229
	0·512	0·446	0·02940	0·1263	0·305
	0·514	0·556	0·02814	0·1213	0·381
	0·521	0·666	0·02720	0·1167	0·454
	0·525	0·779	0·02540	0·1100	0·536
	0·527	0·887	0·02350	0·1028	0·616
	0·530	0·948	0·02230	0·0981	0·662
1200	0·608	0·251	0·03240	0·1379	0·170
	0·612	0·371	0·03070	0·1310	0·251
	0·614	0·464	0·03010	0·1268	0·310
	0·617	0·559	0·02839	0·1208	0·378
	0·620	0·649	0·02740	0·1168	0·439
	0·624	0·742	0·02618	0·1115	0·502
	0·627	0·792	0·02545	0·1086	0·536

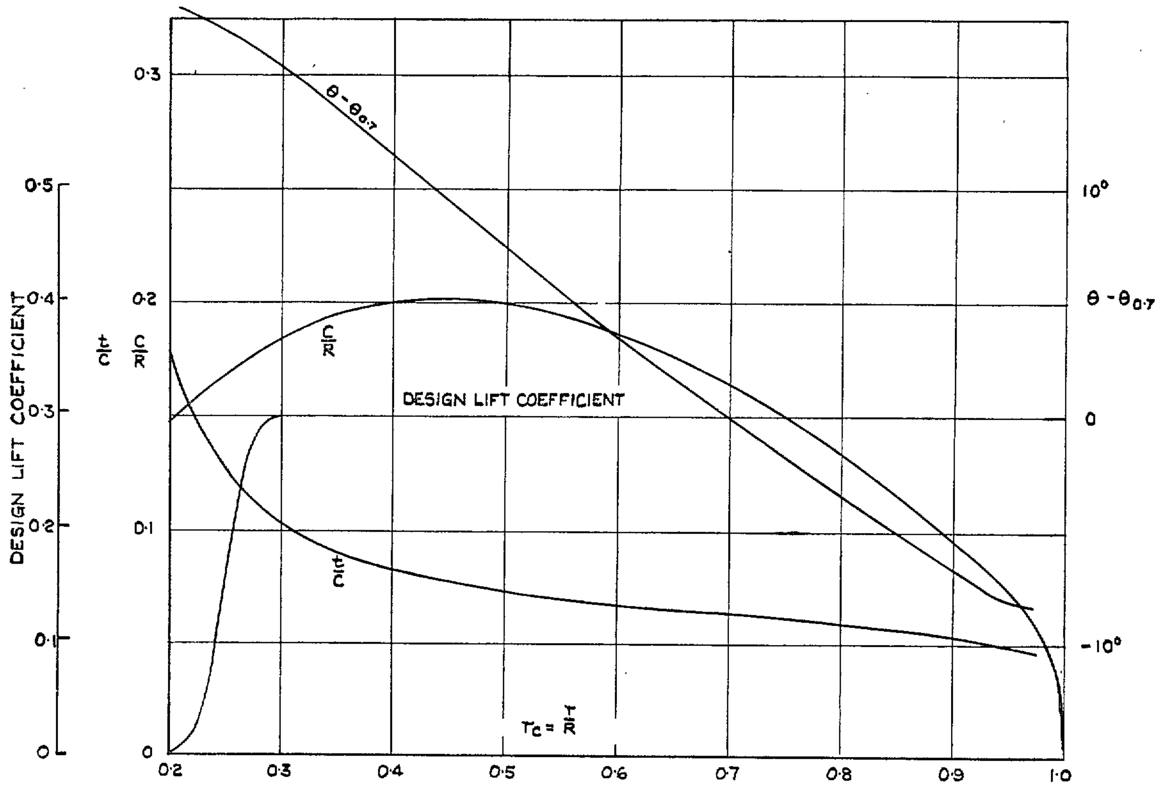

FIG. 1. Blade details of design B.

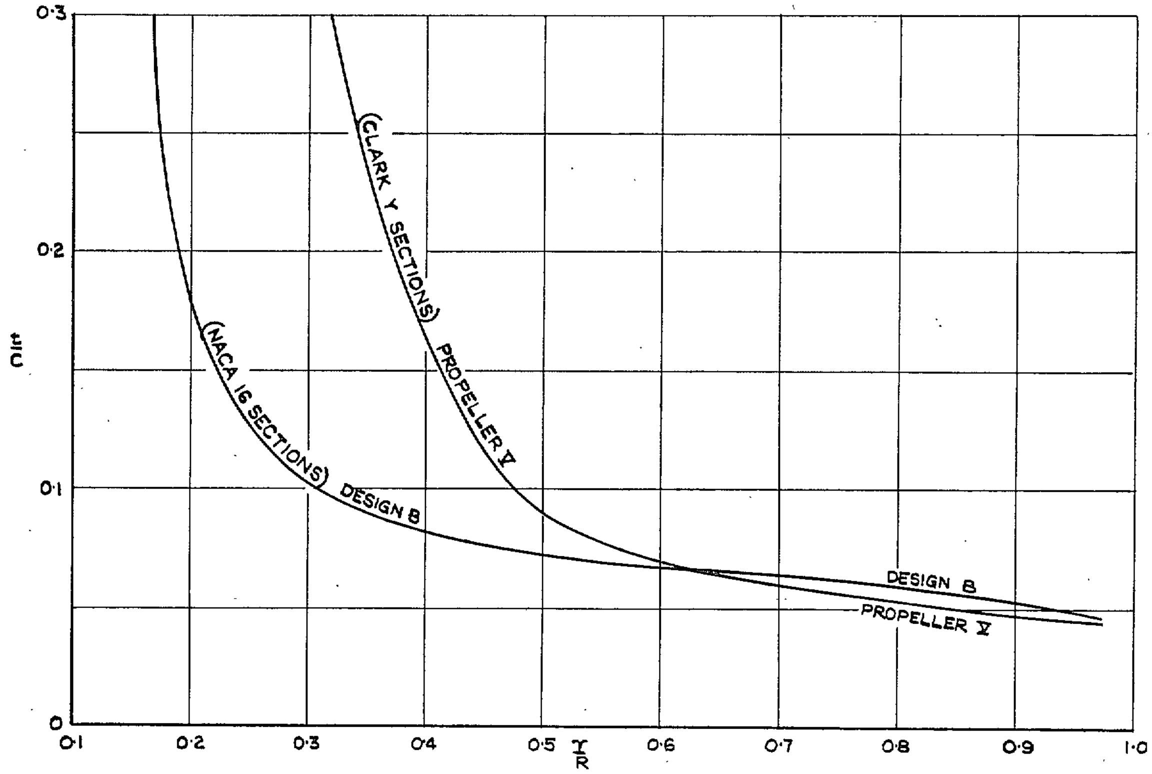

FIG. 2. Comparison of t/c for design B and propeller V.

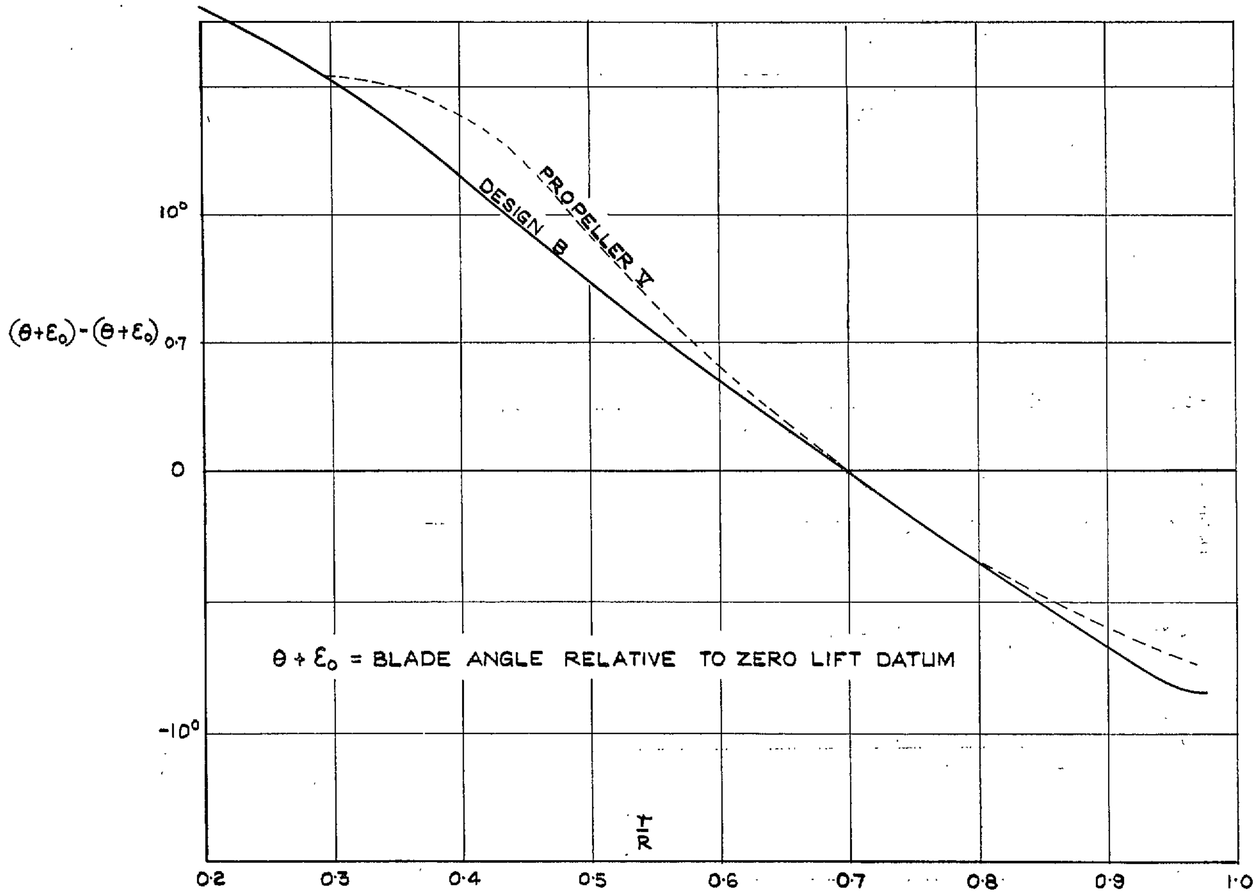

FIG. 3. Comparison of $(\theta - \theta_{0\cdot 7})$ for design B and propeller V.

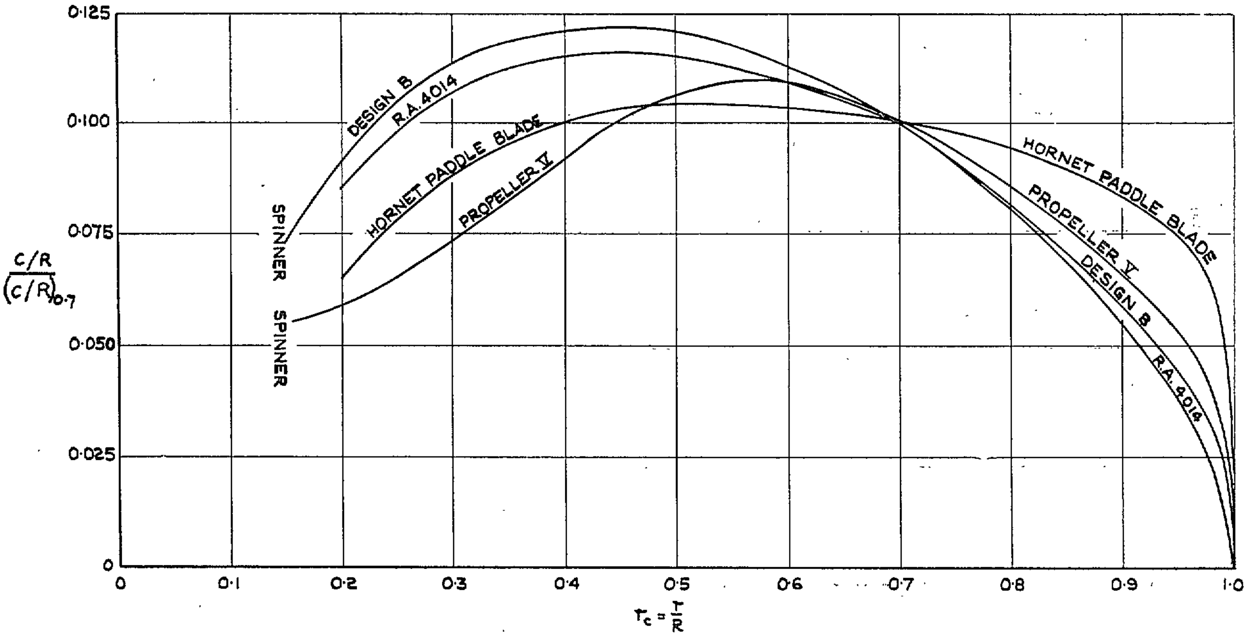

FIG. 4. Comparison of plan form of four propellers.

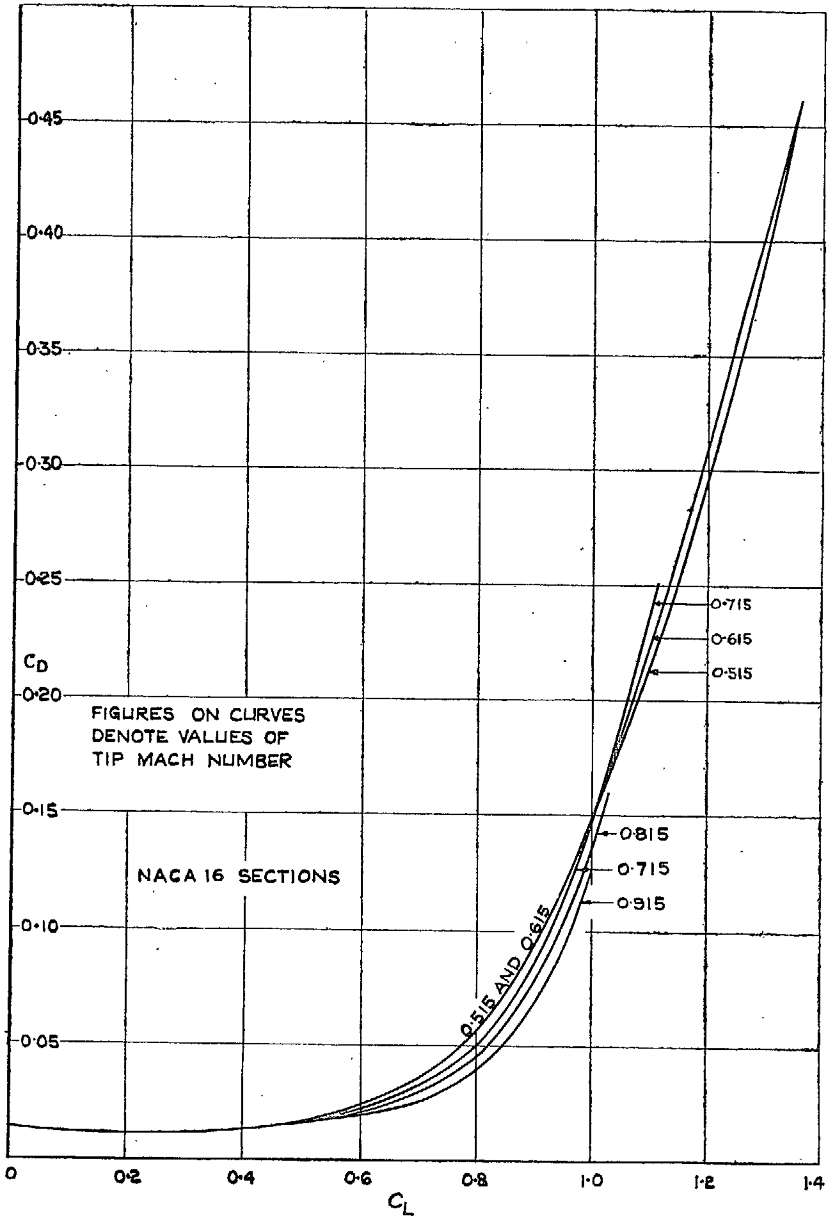

FIG. 5. Mean C_D vs. C_L for design B.

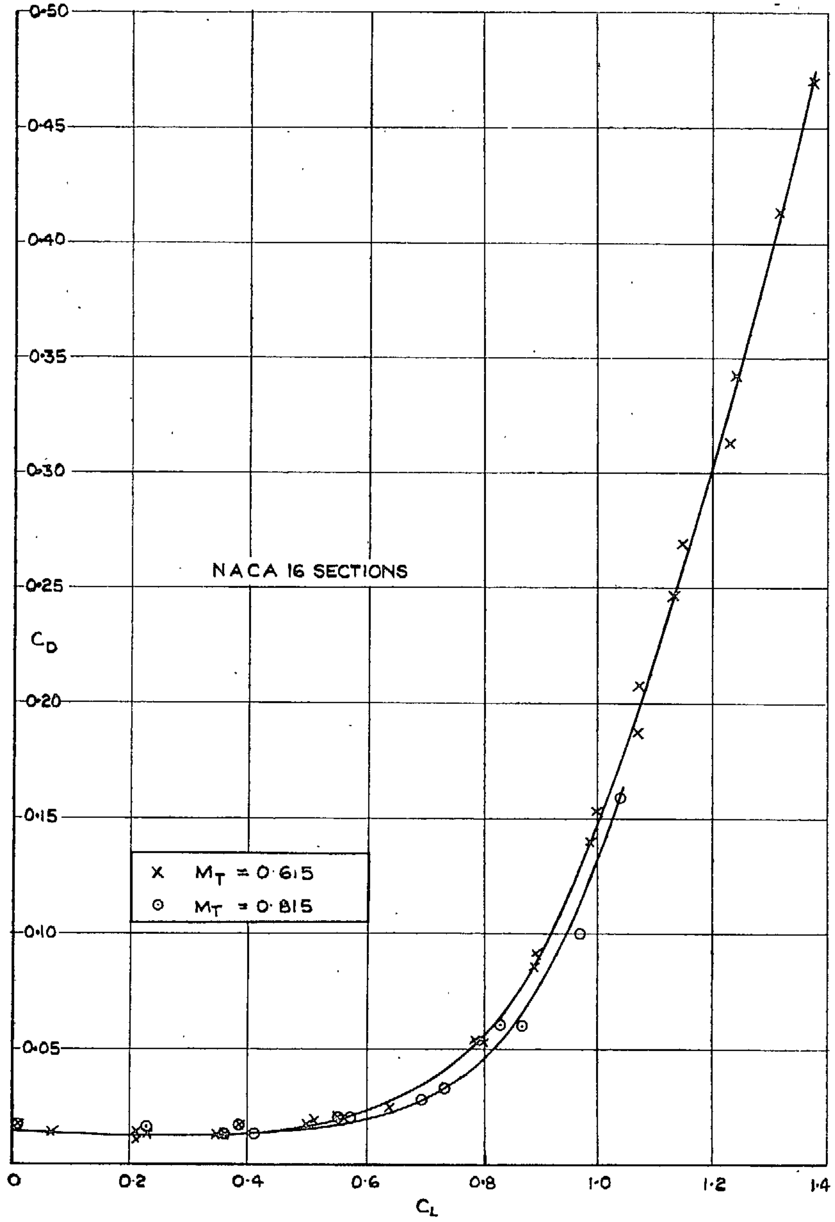

FIG. 6. C_D vs. C_L for $M_T = 0{\cdot}615$ and $M_T = 0{\cdot}815$ showing the scatter of the individual points; design B.

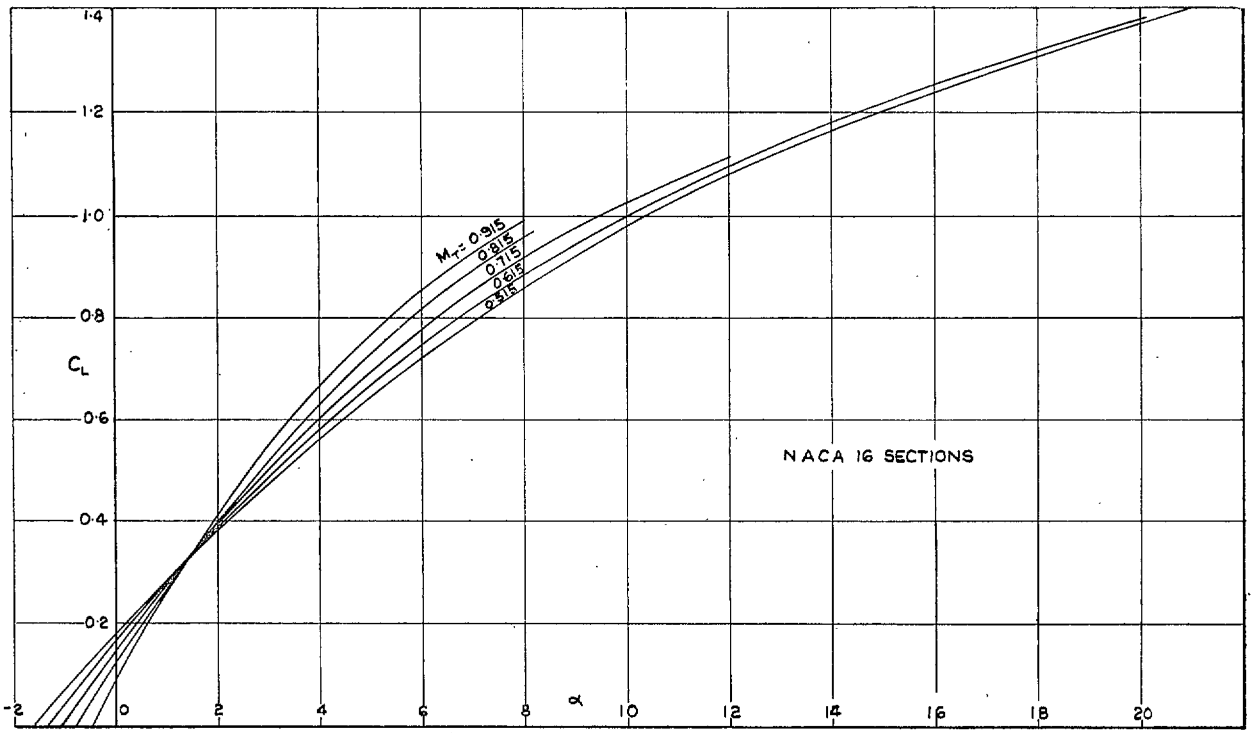

FIG. 7. C_L vs. α at constant M_T for design B.

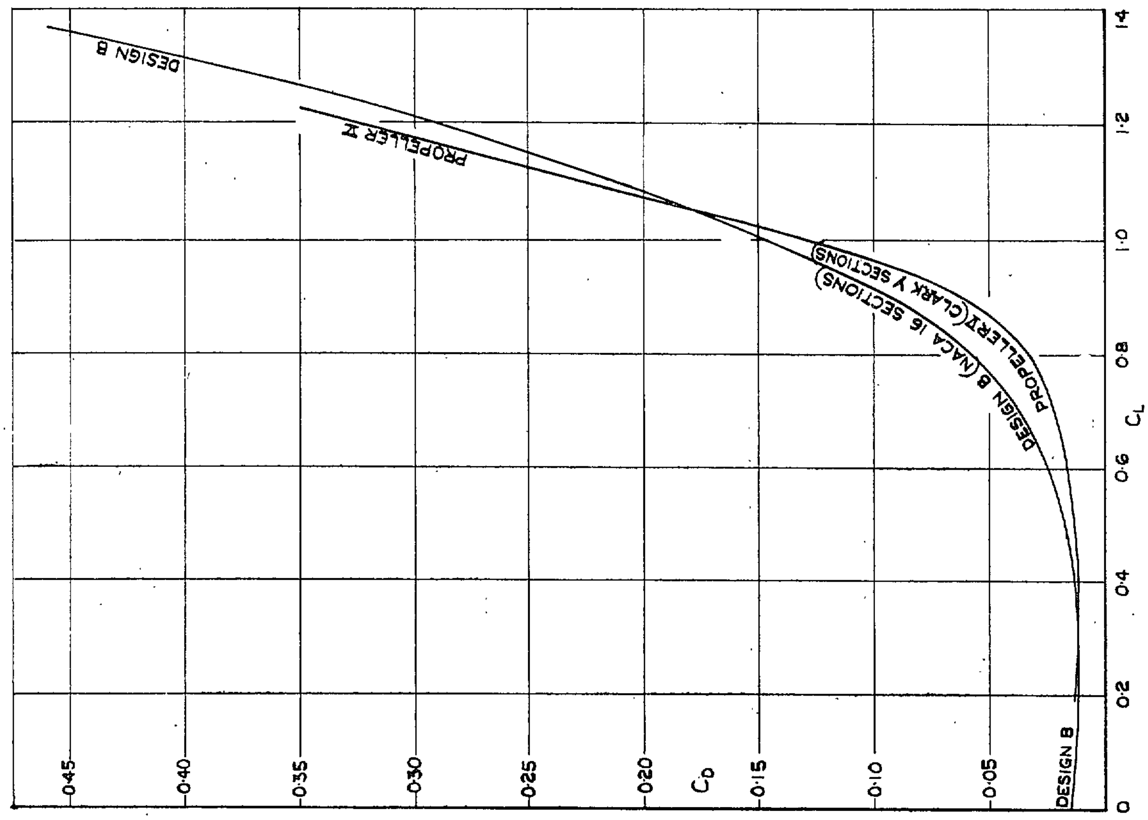

FIG. 8. Comparison at low Mach number of C_D — C_L polars.

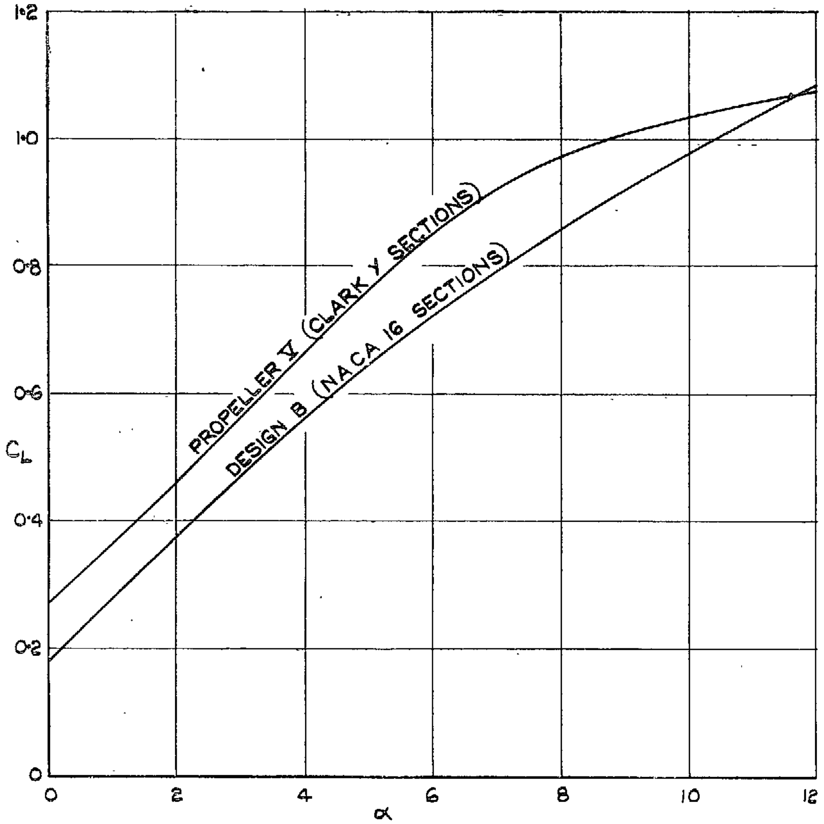

FIG. 9. Comparison at $M_T = 0{\cdot}5$ of C_L vs. α curves of design B and propeller V.

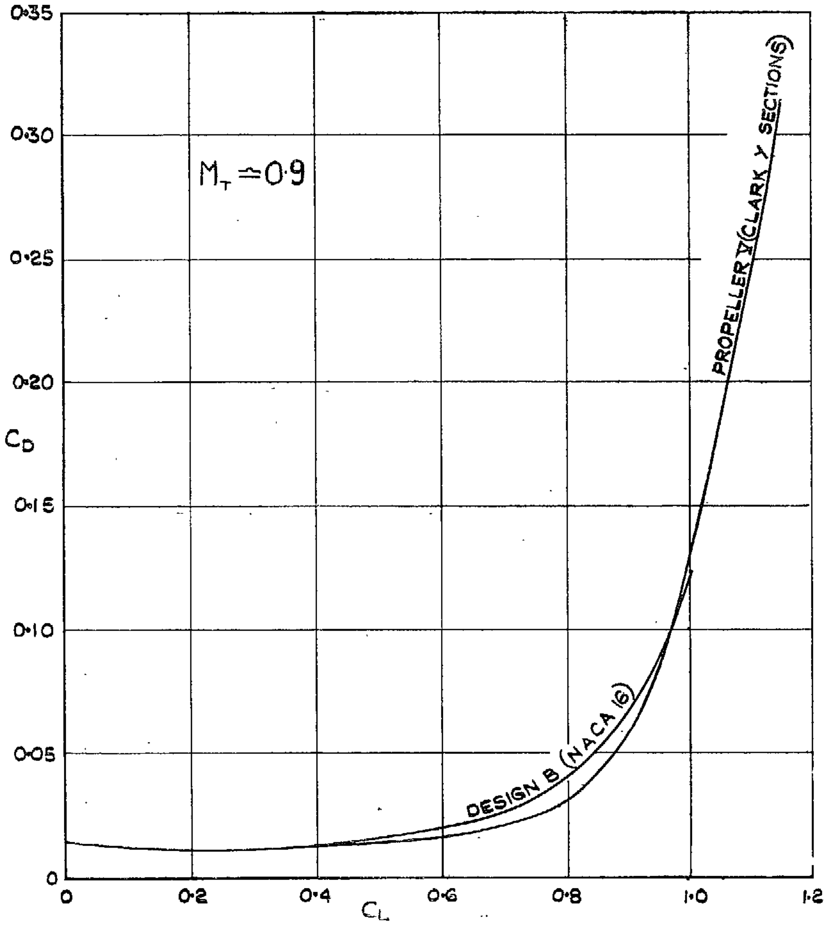

FIG. 10. Comparison at high Mach number of $C_D - C_L$ polars.

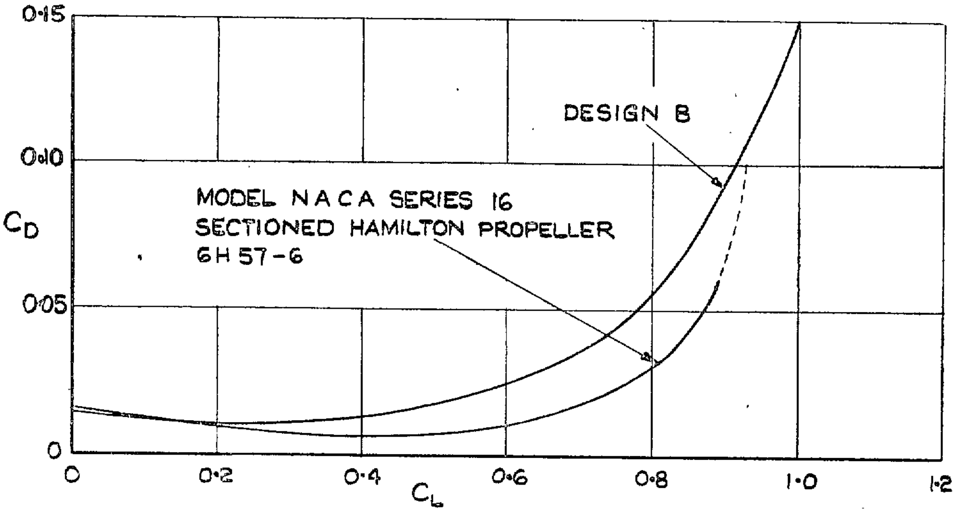

FIG. 11. Comparison of C_D vs. C_L curves for design B and for a model NACA series 16 propeller of a higher design C_L.

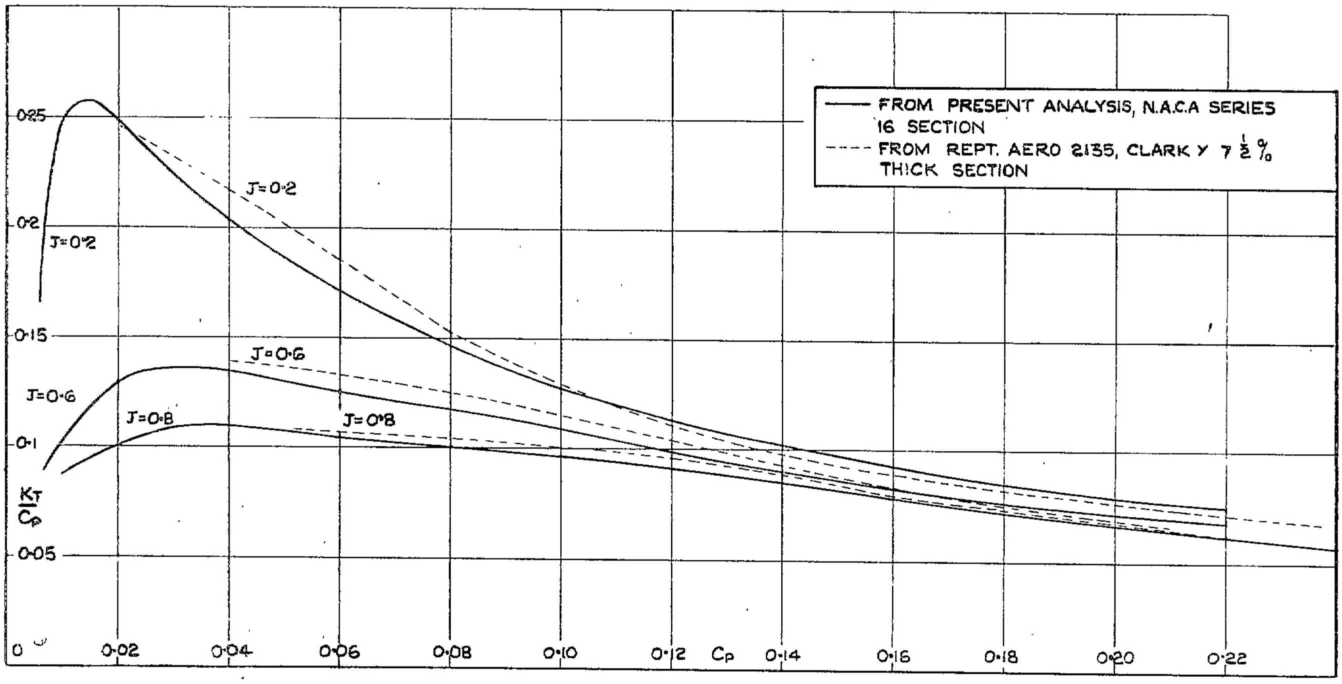

FIG. 12. Take-off thrust characteristics for a 3-bladed propeller solidity = 0·09 at the 0·7 radius.

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